

Dear Graham,

Thank you for your positive feedback on our manuscript. Please find below our detailed responses to your comments. Your original comments are shown in blue, and our replies are in black.

1) Manuscript title, lines 1-4. (title needs further amending).

The title was revised following the initial Topical Editor review, primarily to ensure adherence to the GMD policy, for then having an indicator “ARG2000” to denote a specific version of the activation parameterization, with also the version number for the host UK Met Office Unified model (v13.0). However, further slight amendment is needed, as although technically not grammatically incorrect, the statement made there does not actually summarise what the manuscript finds. The manuscript type is model evaluation paper, and it’s this specifics of the evaluation that needs to be stated within the title there. Specifically, please change “Modifying the. . .” Instead to “Assessing modifications to the. . .”. The grammar of the statement also is not great, and please change “impacts simulated cloud radiative effects” instead to “to improve simulated aerosol-cloud radiative effects”. The words “shown” and “the” should also be deleted from the parentheses to keep the title concise.

We thank you for this suggestion. Based on your suggestion the title is changed to:

“Assessing modifications to the Abdul-Razzak & Ghan aerosol activation parameterization (version ARG2000) to improve simulated aerosol-cloud radiative effects (in UK Met Office Unified Model, version 13.0)”

2) Section 3.2, lines 238

This equation has been added following Reviewer 2’s comments (see general comments above), but the formalism here for the summation indices needs to be improved. With this being a specialist model development journal the formalism ought to be more precise, so please use sub-script i rather than i in parentheses for each term.

We thank you for the suggestion. We have fixed the subscripts based on your suggestions.

3) Section 3.2, lines 238-241

Further to comment 2, the variable names here “cf” and “Pr” should be presented with just 1 main symbol to denote them, with subscripts for indicating any secondary specifications from the primary quantity denoted. There are 2 instances here where that’s not the case, the “cf” for “cloud fraction” and the “Pr” for probability. In both cases there is a recognised roman letter that tends to be used within equations, (capital F for cloud fraction, and capital P for probability), and then the secondary aspects should only be communicated via sub-scripts. Since the cloud fraction is clarified to be liquid cloud fraction, I suggest sub-script lc for liquid cloud, with a comma then to the sub-script I for the summation (i.e. $F_{subscript\,cl,I}$). Although $Pr(i)$ represents a probability for photon transfer, suggest to denote simply as $P_{subscript\,I}$ to focus the main attention on the other variables, these being the primary quantities to consider. Please also amend the text on lines 240-241 accordingly.

Based on your suggestions, we have modified the equation and the associated text. See line 235 of the revised manuscript. In the tracked changes document, the old equation is shown in red, and the updated equation is shown in blue.

4) Section 3.2, line 267-268

Be more specific here, re: “in the cloudiest regions which most affect the global average” The North Pacific has the region of persistent marine stratocumulus off the coast of the Pacific Northwestern US, and I guess that will be one of the “poleward of 30N cloudiest regions” you mean there, right? Are there similarly 1 (or possibly 2) other regions of persistent low cloud that could be stated there (e.g. within the North Atlantic?)

Thank you for this helpful suggestion. Indeed, the region of persistent marine stratocumulus off the coast of the Pacific Northwestern United States is one of the cloudiest areas poleward of 30°N to which we refer. In addition, the North Atlantic, particularly the region off the coast of Western Europe and the northwestern Atlantic near Newfoundland, represents another key area of persistent low-level cloud cover. We have revised the text to explicitly mention these two regions for greater clarity. In line 260 of the revised manuscript, we add the following:

“Poleward of 30° latitude, in the cloudiest regions (such as the coast of the Pacific Northwestern United States, the coast of western Europe, or Newfoundland in the northwestern Atlantic, for example) which most affect the global average, our updated ARG parameterization leads to an improvement in the NMB...”

5) Section 3.2, lines 279-280

The “We conduct a sensitivity study by filtering out. . .” needs to be re-worded – since this is 1 model run, the “study” is too big a word. I guess you mean “sensitivity experiment” here, right?. With this sensitivity added from one of Reviewer 2’s comments (RC2-MC1), it’s important to mention this is to assess the temporal sampling. Suggest to re-word as “To assess temporary sampling in the monthly means, we carried out a sensitivity experiment, filtering out. . . .” 6) Section 3.2, line 285-286

Thank you for the suggestion. We agree that ‘sensitivity experiment’ is a more appropriate term in this context. However, we believe that ‘temporal sampling’ refers to the frequency of data averaging over time. Since we consistently use monthly averaged model data, this term does not apply here. Instead, we are evaluating the sensitivity of N_d to the filtering of the liquid cloud fraction. Accordingly, on line 274 of the revised manuscript, we have revised the text to read:

“To understand the impact of this cloud fraction threshold on the temporally averaged N_d , we design a sensitivity experiment by filtering out the bottom 25th percentile of weights within each month ...”

Further to comment 5, with RC2’s comments, re-word “While our investigation remains approximate..” to be clear this is an alternate methodology: “Whilst this alternate methodology is approximate, it provides an indication of the sensitivity to the temporal sampling, and the results indicate only a modest change (12.5%), not changing the results substantially.”

We thank you for this suggestion. We have reworded the sentence to clarify that this represents an alternative methodology. However, we respectfully disagree with the characterization of the changes as “modest”. Based on the updated NMB and RMSE values, we believe that the changes are minimal. Accordingly, on line 280 of the revised manuscript, we have added the following:

“Although this alternative methodology remains approximate, it illustrates the sensitivity of the cloud fraction threshold to N_d . However, we did not observe significant changes in the results. Therefore, ...”

7) Section 3.2, line 289: “The spatial pattern of the bias in Figure 3 are consistent with. . . .” “The spatial pattern of the CDN biases (Figure 3), are consistent with. . . .”

Line 285 of the revised manuscript is changed according to your suggestion.

8) Section 3.2, line 290: “the biases likely originate in aerosol modelling unrelated to the activation”, The word “likely” is too strong an association here, and this is not evidenced in the manuscript. The biases could also potentially originate in the cloud processes, I’d argue with equal probability. Please change to “. . . the biases are quite likely unrelated to the activation parameterization, i.e. some more general bias (e.g. in either aerosol or cloud)”

We thank you for this suggestion. In line 286 of the revised manuscript, we add the following:

“The biases quite likely originate from aerosol modeling, cloud processes or updraft speeds, unrelated to the activation parameterization.”

9) Section 3.2, lines 292-293: “it is still helpful to understand the impact of our improved functions”

As mentioned in the general comments, please change all instances of “our results”, “our method” etc. (too colloquial), needs to be informal/neutral language in peer-reviewed journal article.

The wording “improved functions” also pre-judges the outcome of the results, and although the revised title states this is the aim, this should also be moderated to remain “the new parameterisation” or “the revised parameter settings” or parameter ranges etc.

Thank you for the suggestion. We have carefully revised the manuscript to replace instances of ‘our results’, ‘our method’, and similar phrases with more neutral and formal language appropriate for GMD. Also in line 289 of the revised manuscript, we have changed ‘improved functions’ to ‘updated functions’. We do not think that parameter is the right word for f and g , since these are functions of the mode width.

10) Section 3.2: line 322, “direct radiative forcing” → “aerosol-radiation interaction radiative effect” and “cloud radiative forcing” → “aerosol-cloud interaction radiative effect” (or “effective radiative forcing” if appropriate). The preceding sentence to this (on lines 320-321) is clear in referring to aerosol radiative forcings, and there also specifies with the IPCC report terminology “effective radiative forcing”. This follow-on sentence needs also to use the approved terminology (direct → “aerosol-radiation interaction”, and indirect or cloud radiative effect → “aerosol-cloud interaction” radiative effect. And also the instances of “direct” and “indirect” on line 324.

Thank you for raising this concern. Based on your suggestions, the text in line 317 of the revised manuscript now reads:

“The Sixth Assessment Report (AR6) of the Working Group I (WGI) of the Intergovernmental Panel on Climate Change (IPCC) estimates the effective radiative forcing due to aerosol-radiation interaction at -0.3 (-0.6 to 0.0) Wm^{-2} , and the effective radiative forcing due to aerosol-cloud interaction at -1.0 (-1.7 to -0.3) Wm^{-2} (Forster et al., 2021) over the industrial era (1750-2014). In the nudged simulations, we may not capture all adjustments (Zhang et al., 2014), and hence do not use the term ‘Effective Radiative Forcing’, but the simulated aerosol-radiation and aerosol-cloud radiative forcings are reasonable at -0.20 and -0.95 Wm^{-2} respectively.”

11) Section 3.2, line 350 to 364, Further to the above please change the several instances of “our” in this paragraph to the impersonal “the” (line 350, line 356, line 358, line 362). Change also “Like several other recent studies (for example Christensen et al., 2023), our results underline the importance of ...” to “Several other studies (e.g. Christensen et al., 2023) have highlighted the importance of. . .”

We thank you for the suggestion. We have replaced “our” with “the” in all four instances as recommended. However, regarding the final sentence, we believe it is important to emphasize that our findings are in line with previous studies, rather than implying that previous studies support our work. Therefore, we have retained the original sentence structure at line 359 of the revised manuscript.

For the “Our proposed changes are extremely simple”, suggest simply to delete that, beginning the paragraph “In all modal aerosol microphysics models we are aware of”.

Sentence deleted according to your suggestion.

However that sentence needs to be clarified to climate model aerosol schemes. There are certainly modal aerosol microphysics schemes in regional air quality models that are generalisable to variable mode widths (e.g. see Figure 4 of Whitby, E. et al., 2002, and see also Whitby E. et al., 1991; Seigneur et al., 1986).

We thank you for bringing this to our notice. Based on your suggestion, in Line 348 of the revised manuscript, we have updated the text to:

“In most of the modal aerosol microphysics models used within climate and weather models that we are aware of...”

12) Caption to Figure S8: Re-word the start of the penultimate sentence, currently worded as “To prepare this figure from that diagnostic, for each month we find. . .”. The text explaining the method seems slightly oblique also. Suggest to replace this last sentence with “For this Figure, the model CDN is diagnosed with different temporal sampling, omitting gridboxes with less than 25% liquid cloud fraction (see section 3.2).”

We thank you for your suggestion. However, we do not omit the gridboxes with less than 25% cloud fraction. As mentioned in the main text, we omit only those gridboxes where the ‘weight’ (as defined in Equation 2) is lower than the 25th percentile of weights in all the gridboxes. Hence, mentioning cloud fraction would be inappropriate. However, we agree that the last line can be improved. Hence, we update the figure caption in the revised manuscript as follows:

“For this figure, we use this monthly diagnostic to identify the 25th percentile of the weight across the entire domain and exclude grid boxes with weights below this threshold.”

References

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- Zhang, K., Wan, H., Liu, X., Ghan, S. J., Kooperman, G. J., Ma, P.-L., Rasch, P. J., Neubauer, D., and Lohmann, U. (2014). Technical note: On the use of nudging for aerosol–climate model intercomparison studies. *Atmospheric Chemistry and Physics*, 14(16):8631–8645.